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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04R 25/00

A1

(11) International Publication Number: WO 98/27787

(43) International Publication Date: 25 June 1998 (25.06.98)

(21) International Application Number: PCT/EP96/05623

(22) International Filing Date: 14 December 1996 (14.12.96)

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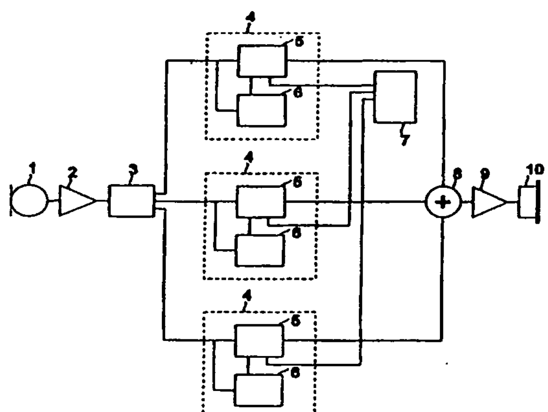
(81) Designated States: AU, CA, JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: HEARING AID WITH IMPROVED PERCENTILE ESTIMATOR



(57) Abstract

The invention relates to a hearing aid, preferably a programmable hearing aid, having at least one microphone (1), at least one signal processor with at least one channel, an output amplifier (9) and an output transducer (10), at least one of the channels containing a signal processing circuit (4) with at least one percentile estimator (6) for the continuous determination or calculation of at least one percentile value of the input signal from a continuous analysis and evaluation of the frequency and/or amplitude distribution of the input signal, whereby the percentile value(s) serve either directly or indirectly as control signals for controlling the gain and/or the frequency response of the electronic processing circuit, the percentile estimator (6) consisting essentially of a comparator stage (12) with two inputs and two outputs, the first input being directly or indirectly connected to the input of the hearing aid, its two outputs controlling a first control stage (13) the output signals of which control a first integrator (14), the output of which, directly or indirectly, conveys a control signal to the signal processing circuit (5) and the second input of the comparator stage. The invention comprises at least a second control stage (16) connected to the first control stage (13), and at least one additional integrator (17) controlled by the second control stage (16), the output of which is connected to a further input of the second control stage (16) and to a multiplier stage (15) interconnected between the first control stage (13) and the first integrator (14).

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Hearing aid with improved percentile estimator

Bakground of the invention

The invention relates to a hearing aid, preferably to a programmable hearing aid having at least one microphone, at least one signal processor with at least one channel, an output amplifier and an output transducer, at least one of the channels containing a signal processing circuit with at least one percentile estimator for the continuous determination or calculation of at least one percentile value of the input signal from a continuous analysis and evaluation of the frequency and/or amplitude distribution of the input signal, whereby the percentile value(s) serve either directly or indirectly as control signals for controlling the gain and/or the frequency response of the electronic processing circuit, the percentile estimator consisting essentially of a comparator stage with two inputs and two outputs, the first input being directly or indirectly connected to the input of the hearing aid, its two outputs controlling a first control stage the output signals of which control a first integrator, the output of which, directly or indirectly, conveys a control signal to the signal processing circuit and the second input of the comparator stage.

Percentile estimators which may also be used in hearing aids, are known in principle from US-A 4.204.260.

Clinical tests have shown, that the use of correctly fitted hearing aids, i.e. hearing aids with constant gain, independent of signal-levels, in noisy as well as quiet surroundings are superior to hearing aids with an automatic gain control, with respect to speech comprehension. However, while linear hearing aids require the user to adjust the volume control dependent on the actual listening environment, hearing aids with automatic gain control adapt themselves to the environment and thereby clearly improve the ease-of-use.

Based on the clinical tests mentioned above, the percentile estimators have to work very slowly to achieve an almost constant gain for speech signals. This works very well if one stays in an environment where the level of sound is not varying too much, but the long response times of the system will in some cases not adapt fast enough to changes in environment, resulting in phrases not being heard.

A common problem is the situation where the user of the hearing aid is yelling a message to a distant person. This will increase the percentile estimate and hence reduce the gain in the hearing aid. Since the percentile estimator works slowly, the gain stays reduced for a while, and the hearing aid user will not be able to hear the distant person answering, because the resulting output of the hearing aid will be very low, perhaps even below the user's hearing threshold level.

On the other hand one could let the percentile estimators work fast, which obviously will make the system adapt faster to changes in environment, but the gain can then not be considered constant for the speech signals. The fast gain adjustment of the system will cause "pumping"-effects, which can be very annoying for the user, especially in noisy surroundings, and may result in loss of speech comprehension.

In an automatic gain control system for hearing aids, percentile estimators operating on the present signal in one or more channels may be used for controlling the gain of the electronic signal processors. Such a system is f.i.

disclosed in WO 95/15668 of applicant.

Summary of the invention

It is an object of the present invention to create an improved percentile estimator, particularly for use in hearing aids of the kind referred to above, which makes it possible for the hearing aid to adapt fast to changes in the environment, while maintaining a slow response when operating on continuous signals, e.g. speech signals in a steady environment.

This is achieved in a hearing aid as referred to above in accordance with the present invention with a percentile estimator structure having at least a second control stage connected to the first control stage, and at least one additional integrator controlled by the second control stage, the output of which is connected to a further input of the second control stage as well as to a multiplier stage, interconnected between the first control stage and the first integrator.

It is of particular importance that the second control stage supplies a rectified and scaled version of the predefined parameters of the first control stage, generating a positive control signal for the second integrator and a forward reset signal to said second integrator for establishing a predefined minimum value of said integrator whenever the output signal of the first control stage changes.

Other characteristics of the invention and advantageous further embodiments thereof are subject of the remaining claims.

Brief description of the drawings

In the drawings

Fig. 1 shows a schematic circuit diagram of a multichannel hearing aid using percentile estimators;

Fig. 2 shows a schematic diagram of the principle of a percentile estimator;

Fig. 3 shows, schematically, an improved percentile estimator for hearing aids with two levels in accordance with the present invention;

Fig. 4 shows, schematically, an improved percentile estimator for hearing aids with three levels in accordance with the invention and

Fig. 5 shows a diagram of the operation of a traditional percentile estimator in comparison with the operation of the improved percentile estimator on an actual sound example.

Detailed description of a preferred embodiment of the invention

Fig. 1 shows a principle circuit diagram of a multi-channel hearing aid with one microphone 1 and preamplifier 2, a band split filter 3 for splitting the signals into a number of channels (here 3 is shown), each having a signal processing circuit 4 consisting of a signal processor 5 and a percentile estimator 6, a register 7 for storing parameters related to the basic hearing aid performance, a summing circuit 8, an output amplifier 9 and a receiver 10.

Fig. 2 shows the principle of a traditional percentile estimator 6. Such percentile estimators are known from US-A 4.204.260.

The input signal for the specific channel is led into a detector stage 11, which is not essential for the operation of the percentile estimator, but is preferably used. It could include a rectification for determining the envelope of the input signal, and also a logarithmic conversion to obtain the envelope on a dB-scale, which is commonly used in hearing aids. The output signal from the detector 11 is supplied to a comparator 12 with its two inputs connected to the output from the detector 11 and an integrator 14.

The result of the comparison is supplied to the control stage 13, which in case of the output of the integrator 14 being greater than the output of the detector 11 holds a predefined negative value at its output, causing a decrease of the value stored in the integrator 14, and in the opposite case holds a predefined positive value at its output, causing an increase of the integrator value.

In this way the value present at the output of the integrator 14 will be a percentile estimate of the input signal of the detector 11 and the signal processor 5, the percentile value being dependent on the actual predefined values of the control stage 13.

The output of the percentile estimator 6 is used for controlling the signal processor 5. Clearly, it is possible to include more than one percentile estimator 6 in each channel and let the signal processor be controlled by all of these in combination. In that case,a combination and control logic may be used to combine the output signals of the different percentile estimators.

Fig. 3 shows the principle of an improved percentile estimator in accordance with the invention.

The traditional percentile estimator is modified with a multiplier 15, with its output supplying the integrator 14 and its inputs connected to the output of

the control stage 13 and the output of an integrator 17. The integrator 17 is controlled by a control stage 16 which includes a rectifier 21 and a gain block 22for rectifying and scaling the predefined parameters of the control stage 13 and thereby modifying the timing of the increase and decrease of the integrator 14 and thus the response time of the percentile estimator.

The control stage includes a zero-cross detector 23 which provides a reset pulse for the integrator, which then resets to a predefined minimum value whenever the output from the control stage 13 changes, hence whenever the input sound crosses the percentile estimator level.

The control stage 16 further may include a comparator 24 for checking if the output of the integrator 17 is less than a predefined maximum allowable value 25, in which case the transmission control 26 passes the output of the gain block 22 on to the integrator 17, and in the opposite case passes a value of zero or less on to the integrator 17 in order to prevent further increase of the integrator output.

The effect is an "accelerating" percentile estimator. The short term percentile estimator response time is long, dependent on the minimum value of the integrator 17 and will be dominant when the environment is characterized by a relatively constant sound level, where the input sound level crosses the percentile estimate frequently. The long term response time is relatively short because of the acceleration, and this effect will be of use in cases where the sound level changes, e.g. when communicating with a distant person, as mentioned earlier.

Fig. 4 shows an expansion of the improved percentile estimator by another level by adding a multiplier 18 with its output supplying the integrator 17 and its inputs connected to the output of the control stage 16 and the output of an

integrator 20, which again is controlled by a control stage 19 similar to control stage 16.

Clearly it is possible to expand the number of levels in the improved percentile estimator even more than the three levels shown.

For the traditional percentile estimator of Fig. 2 a percentile level of p percent is obtained by the following formula:

$$p = 100\,u/(u-d)$$

where u is the upward integration value (positive)
d is the downward integration value (negative)

Both u and d in the formula above are defined by the predefined values of the control stage 13.

In the improved percentile estimator, the integration speeds are time dependent. The upward integration speed is determined by

$$u_{result} = u \cdot \int_0^{t_u} k_{16} \cdot |u| \cdot \int_0^{t_u} k_{19} \cdot |u| \, dt \ldots\ldots dt$$

and the downward integration speed is

$$d_{result} = d \cdot \int_0^{t_d} k_{16} \cdot |d| \cdot \int_0^{t_d} k_{19} \cdot |d| \, dt \ldots\ldots dt$$

where k_{16} and k_{19} are the scaling factors in the control stages 16 and 19.

In a "stationary" sound environment, i.e. when the percentile estimate is stable, we have

$$|u| \cdot t_u = |d| \cdot t_d = \text{constant}$$

where t_u and t_d are the collective time intervals over this stable time period in which the integrator integrates upwards and downwards, respectively.

This simplifies the integrations in the formulas above, and yields the following expressions for the integration speeds of the improved percentile estimator:

$$\begin{aligned} u_{result} &= u \cdot k_{16} \cdot |u| \cdot k_{19} \cdot |u| \cdot t_u \ldots\ldots t_u \\ &= u \cdot k_{16} \cdot k_{19} \ldots\ldots \text{constant} \end{aligned}$$

$$\begin{aligned} d_{result} &= d \cdot k_{16} \cdot |d| \cdot k_{19} \cdot |d| \cdot t_d \ldots\ldots t_d \\ &= d \cdot k_{16} \cdot k_{19} \ldots\ldots \text{constant} \end{aligned}$$

Hence, for stationary environments, even though the integration speeds are time dependent, the percentile level can be obtained by the same formula as for the traditional percentile estimator, since a constant multiplied to the integration speeds u and d does not change this formula.

Fig. 5 shows the function of a 2-level improved 90% percentile estimator with an increase from a minimum odB/sec growing 207.36 dB/sec^2 to a maximum of 57.6 dB/sec and a decrease from a minimum odB/sec growing 2,56 dB/sec^2 to a maximum of 6.4 dB/sec.

This is achieved by using a digital implementation with:

a 32 kHz sampling frequency

an upward integration step of u = 5e - 4 in the control stage 13

a downward integration step of d = - 5e - 5 in the control stage 13

a scaling factor of $k_{16} = 1$ in the control stage 16
a predefined minimum value of 0 of the integrator 17
a predefined maximum allowable value of 4 of the integrator 17

The function is compared with a traditional 90% percentile estimator with an increase of 14.4dB/sec and a decrease of 1.6dB/sec.

The comparison is performed on an actual sound example with a duration of 32 secs. The sound level is stepped down 20dB after approximately 7 secs to simulate a change of sound environment.

Note that the improved percentile estimator, because of the increasing integration speed, adapts much faster to change in environment than the traditional one, with respect to sound level increases (see the first 2 seconds) as well as sound level decreases (see the signal behaviour around 7 seconds).

Still, the improved percentile estimator behaves similar to the traditional one in the time range where the percentile estimation in both cases has become "stationary", i.e. from approximately 20secs to 32secs. This is due to the signal crossing the output of the improved percentile estimator, which generates a frequent reset of the integrator speed, and hereby keeps the response time of the percentile estimator long for this signal.

Finally, it may be pointed out that all the parameters of control stages 13 and the scaling factors of control stages 16 and 19 may be preset, may be programmable or may even be program controlled.

The steady progress in the design of very highly integrated circuits may lead to an extremely compact design of hearing aids, incorporating not only the improved percentile estimators for one or several channels but also the micro-

processor and storage means for the necessary operational tools, such as algorithms .

Furthermore it is to be understood that the register 7 in Fig. 1 should comprise all necessary control parameters for the control of the transfer characteristic of the hearing aid, possibly also for various different programmed or programmable environmental listening situations.

PATENTCLAIMS

1. In a hearing aid having at least one microphone (1) for providing an input signal, at least one signal processing channel (4) receiving and processing at least a portion of said input signal to produce at least one output signal, an output amplifier (9) for amplifying said at least one output signal, and an output transducer (10) responsive to the amplified output signal, said at least one channel including a signal processing circuit (5) for processing said input signal portion in accordance with an output signal from a percentile estimator (6), said percentile estimator including a comparator stage (12) for comparing said input signal portion to an integrated value, a control circuit arrangement for providing an integrator control signal in accordance with the results of said comparison, and an ingetrator responsive to said integrator control signal for providing said integrated value to said comparator stage, and as said percentile estimator output to said signal processing circuit, characterized by a first control stage (13) responsive to an output from said comparator stage (12) for providing an integrator control signal representing a value and a direction of integration, a multiplier stage (15) for modifying said value of the integrator control signal of said control stage (13), and by a second control stage (16) responsive to the integrator control signal of the first control stage (13) for controlling a second integrator (17) for providing a modification signal to the multiplier stage (15).

2. Hearing aid in accordance with claim 1, characterized in that the output of the second integrator (17) provides an integrated value signal to a further input of the second control stage (16).

3. Hearing aid in accordance with claim 1, characterized in that the second control stage (16) supplies a rectified and scaled version of predefined control parameters of the first control stage (13), generating a positive control signal for the second integrator (17) and a forward reset signal to said second integrator (17) for establishing a predefined minimum value of said integrator (17) whenever the output signal of the first control stage (13) changes.

4. Hearing aid in accordance with claims 1 and 2, characterized in that the second control stage (16) contains a zero-cross-detector stage (23) coupled between the input of said control stage (16) and a second input of the second integrator (17), providing the reset signal for said integrator (17) for resetting said integrator to a predefined minimum value, whenever the output of the first control stage (13) changes, hence whenever the input sound of the hearing aid crosses the percentile estimator value.

5. Hearing aid in accordance with claim 1, characterized in that the second control stage (16) additionally comprises a rectifier stage (21), a gain block (22) and a transmission control stage (26) controlling the second integrator (17), for rectifying and scaling the predetermined control parameters of the first control stage (13) for controlling the second integrator (17), the output of which is connected with the input of the second control stage (16) by means of a comparator stage (24) for comparing its output with a predefined maximum allowable value (25) to control the passage of the output of the gain block (22) to the second integrator (17) by means of the transmission control stage (26).

6. Hearing aid in accordance with claim 1, characterized by a third control stage (19) connected to the first control stage (13) for controlling a third integrator (20), and a second multiplier (18) connected between the second control stage (16) and the second integrator (17) and also with the output of the third integrator (20), the output of which is further connected to the third control stage (19) for rectifying and scaling the predetermined control parameters of the first control stage (13), generating a positive control signal for the third integrator (20) and a forward reset signal to said integrator for establishing a predefined minimum value of the integrator (20) whenever the sign of the output signal of the first control stage (13) changes.

7. Hearing aid in accordance with claim 1, characterized in that the values of the predefined parameters and/or the predefined scaling factors of the control stages (13, 16, 19) for the control of the integrators (14, 17, 20) may be preset, programmed or programcontrolled.

8. Hearing aid in accordance with claim 1 characterized in that the values of the output signals of the control stages (13, 16, 19) may or may not be equal for the positive or negative changes to be effected in the integrators (14, 17, 20).

9. Hearing aid in accordance with claim 1, characterized in that for the purpose of the continuous determination of a signal sequence from the input signal, a detector stage (11) is connected between the input of the hearing aid and the input of the percentile estimator (6) for mathematical processing of the input signal by way of predefined or predefinable algorithms or calculating rules.

10. Hearing aid in accordance with claim 1, characterized in that for the purpose of the continuous determination of the envelope of the input signal, a rectifier is connected between the input of the hearing aid and the input of the percentile estimator (6) as a detector stage (11).

11. Hearing aid in accordance with claim 1 with at least two channels, characterized in that at least two percentile estimators (6) are connected in parallel in at least two parallel channels covering essentially adjacent frequency bands and in which the outputs of the integrators of these percentile estimators (6) of the respective channels are connected with the inputs of a combination and control logic, said combination and control logi c being connected in turn to the signal processor (5) of the respective channel via at least one control line.

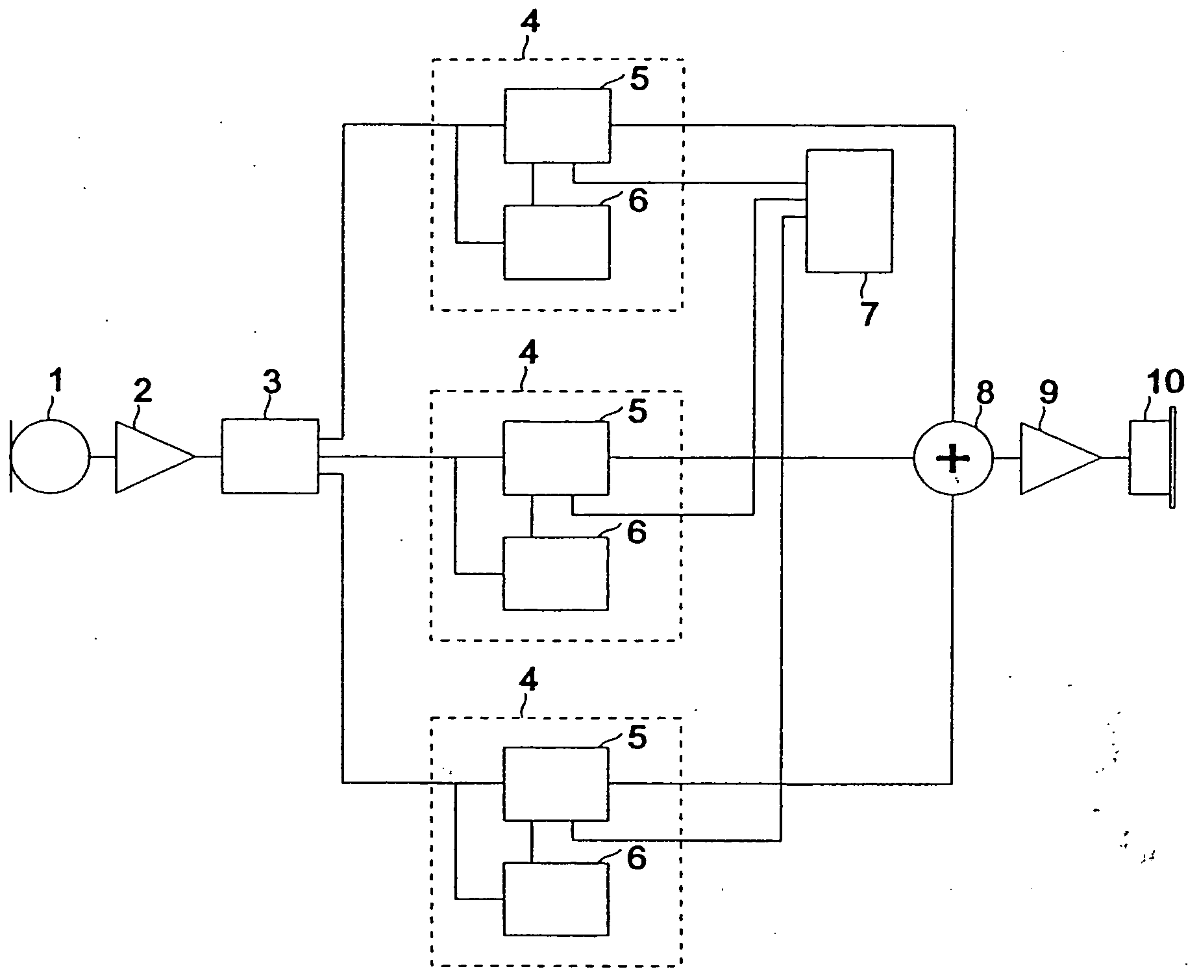

Fig. 1

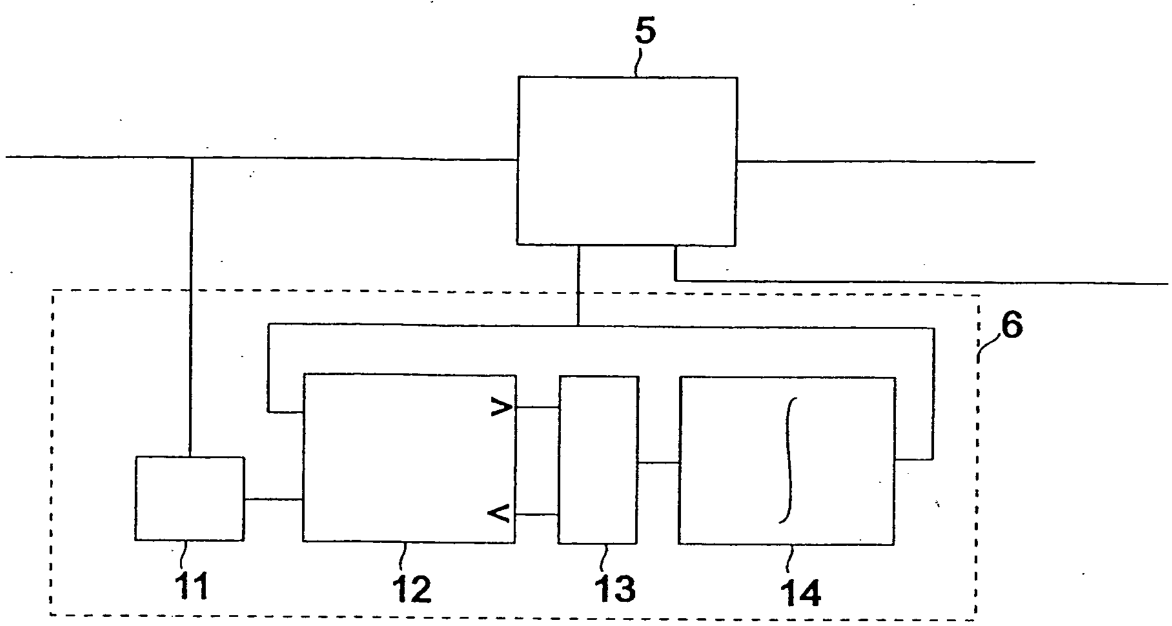

Fig. 2

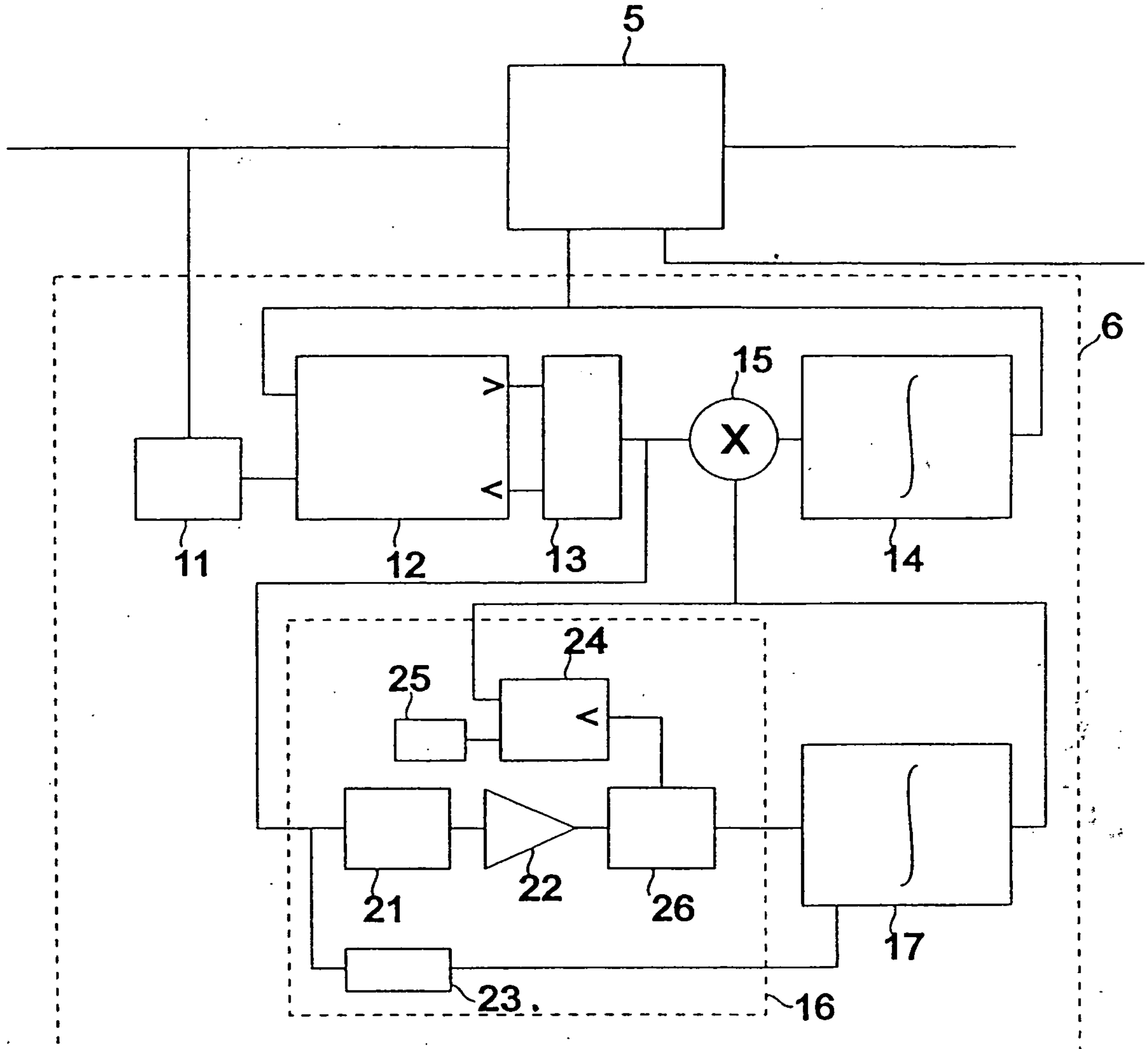

Fig. 3

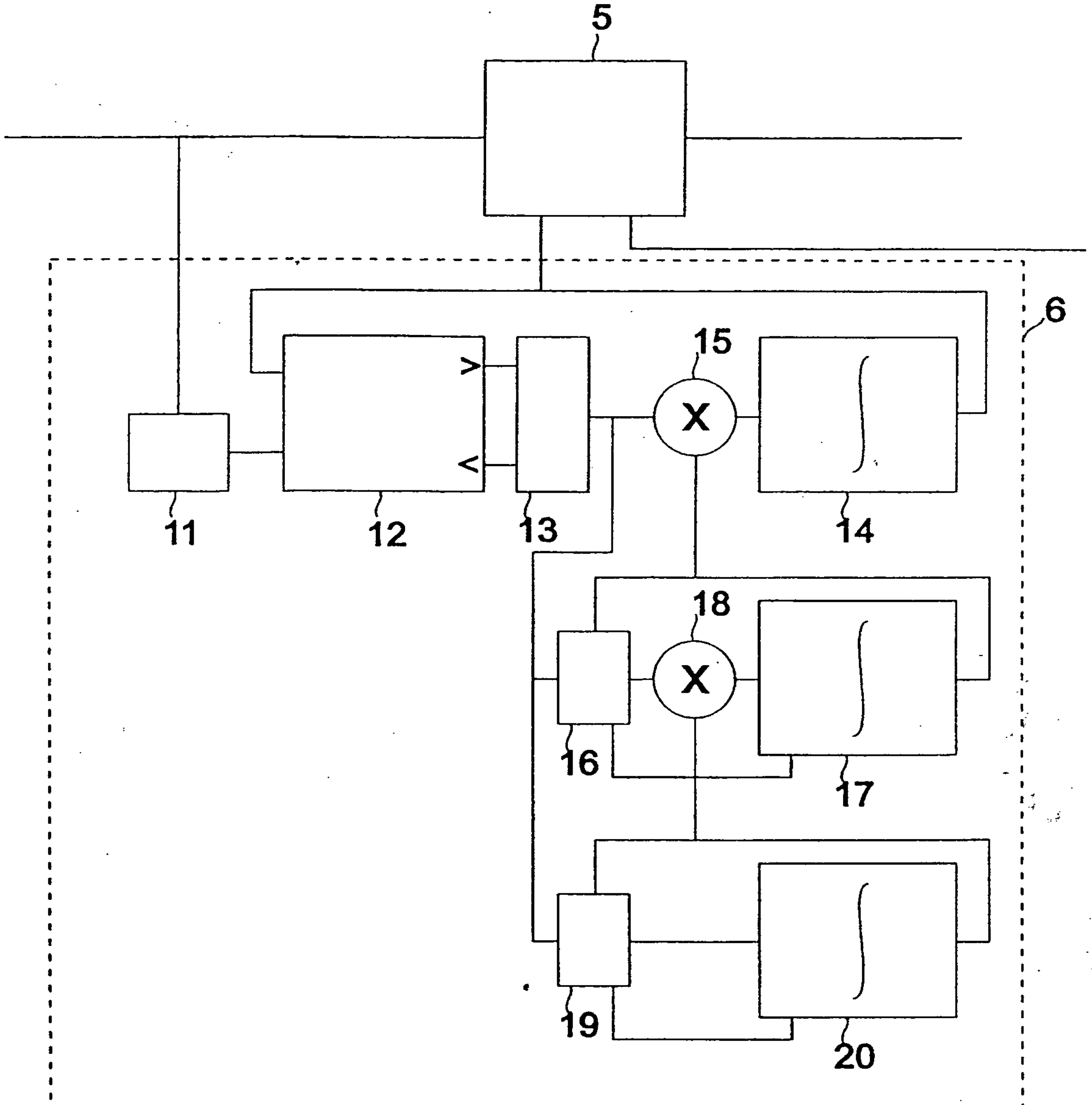

Fig. 4

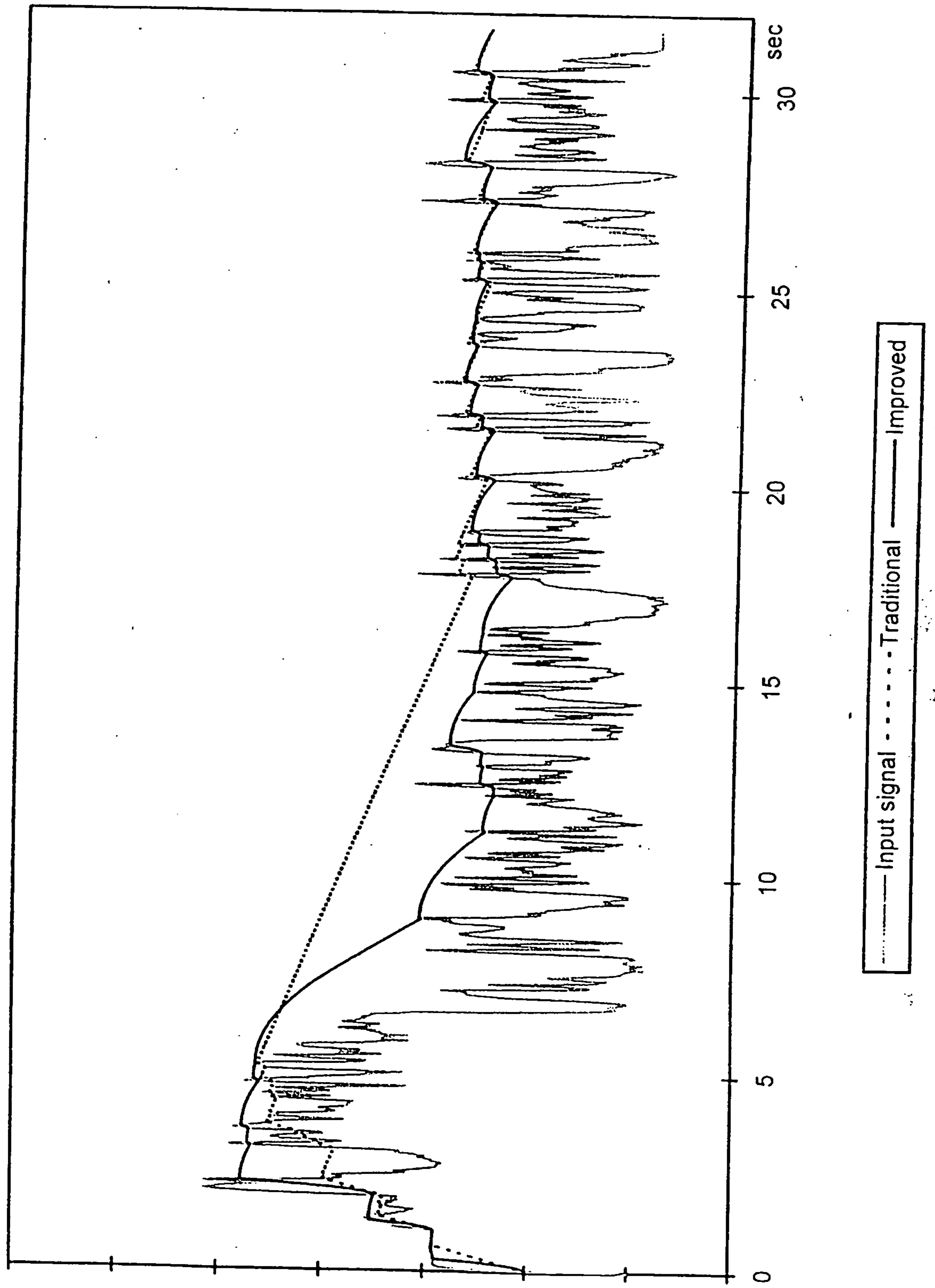

Fig. 5

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04R25/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 95 15668 A (TOEPHOLM & WESTERMANN ;LUDVIGSEN CARL (DK)) 8 June 1995 cited in the application see page 5, paragraph 2 - page 12, paragraph 1; figures 1-7 ---	1-11
A	EP 0 282 335 A (MINNESOTA MINING & MFG) 14 September 1988 see column 1, line 5 - column 2, line 59 see column 7, line 57 - column 9, line 52; figures 8,9 ---	1
A	US 5 027 410 A (WILLIAMSON MALCOLM J ET AL) 25 June 1991 see column 1, line 11 - line 54 see column 13, line 16 - column 16, line 58; figures 7-12 --- -/--	1

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
27 February 1997	27.03.97

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 204 260 A (NYSEN PAUL A) 20 May 1980 cited in the application see column 2, line 7 - column 3, line 64; figures 1-3 -----	1

1.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 96/05623

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9515668 A	08-06-95	DE 4340817 A	08-06-95
		AU 7497694 A	19-06-95
		CA 2172365 A	08-05-95
		EP 0732036 A	18-09-96
EP 0282335 A	14-09-88	US 4823795 A	25-04-89
		AU 605835 B	24-01-91
		AU 1211988 A	15-09-88
		CA 1312136 A	29-12-92
		DE 3854097 D	10-08-95
		DE 3854097 T	07-03-96
		JP 63242253 A	07-10-88
US 5027410 A	25-06-91	WO 9005437 A	17-05-90
US 4204260 A	20-05-80	AU 3691678 A	13-12-79
		GB 2000302 A,B	04-01-79

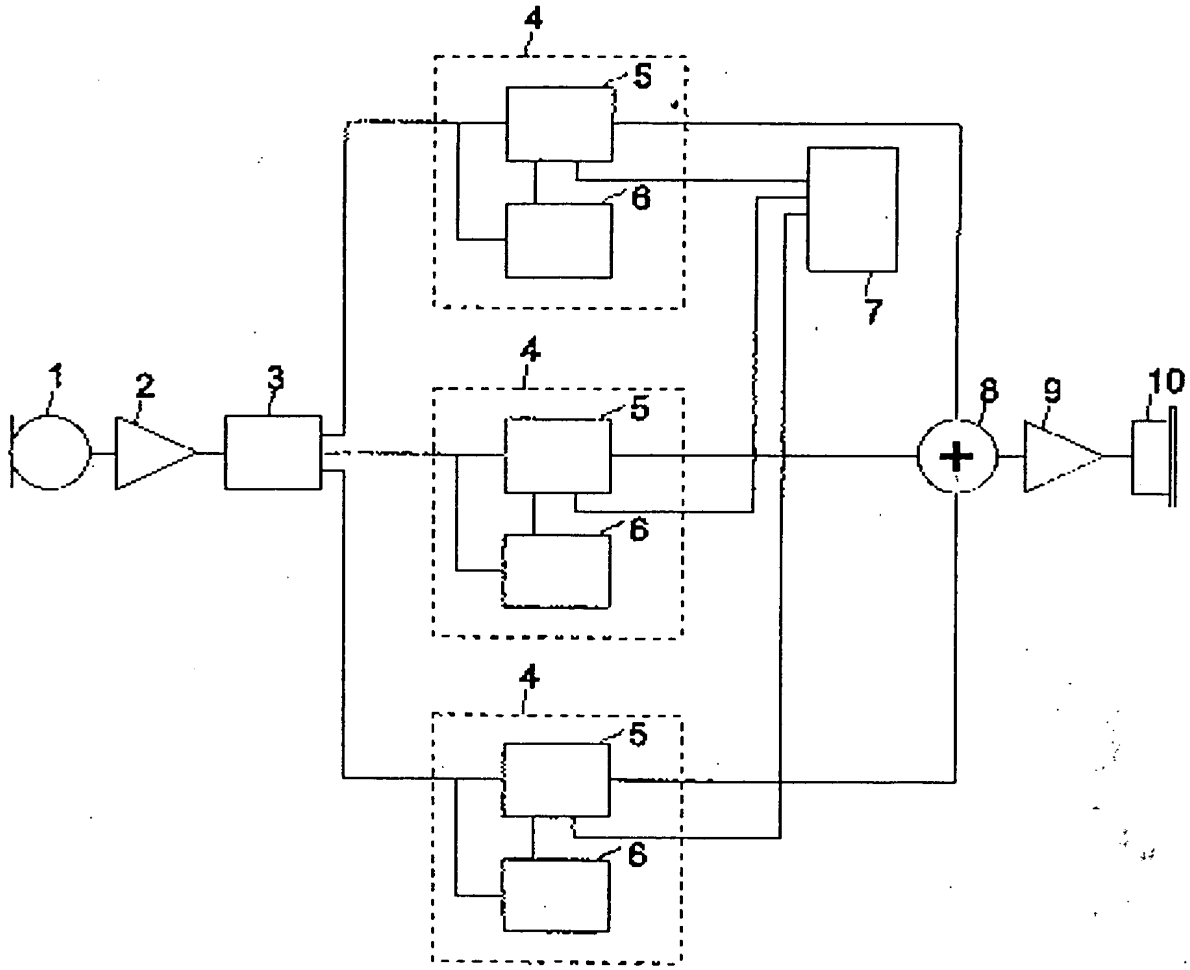

Fig. 1

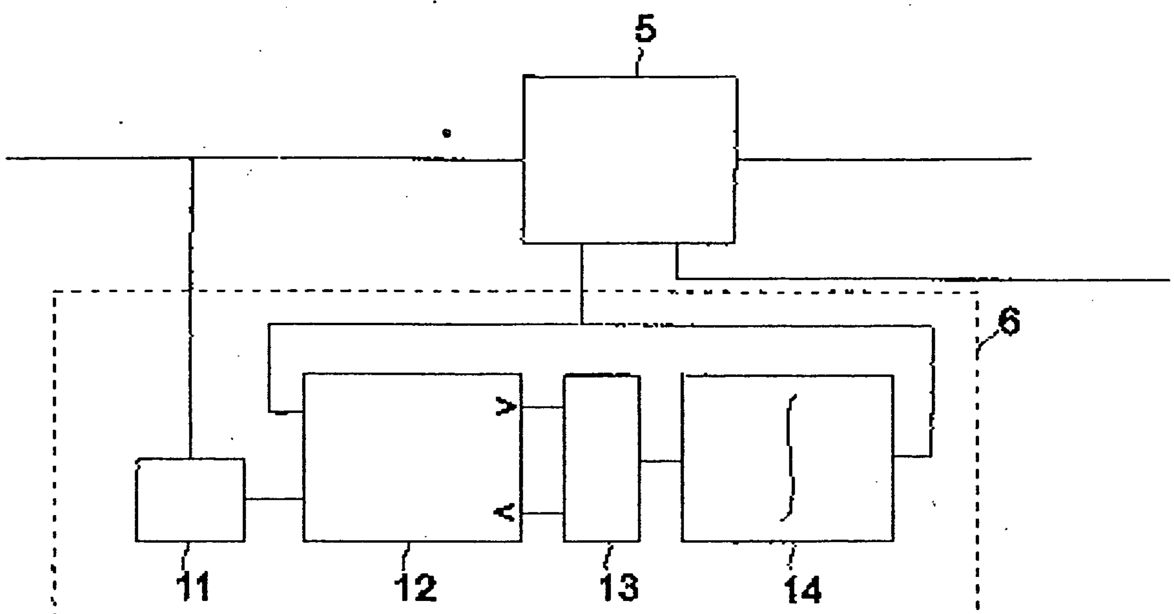

Fig. 2

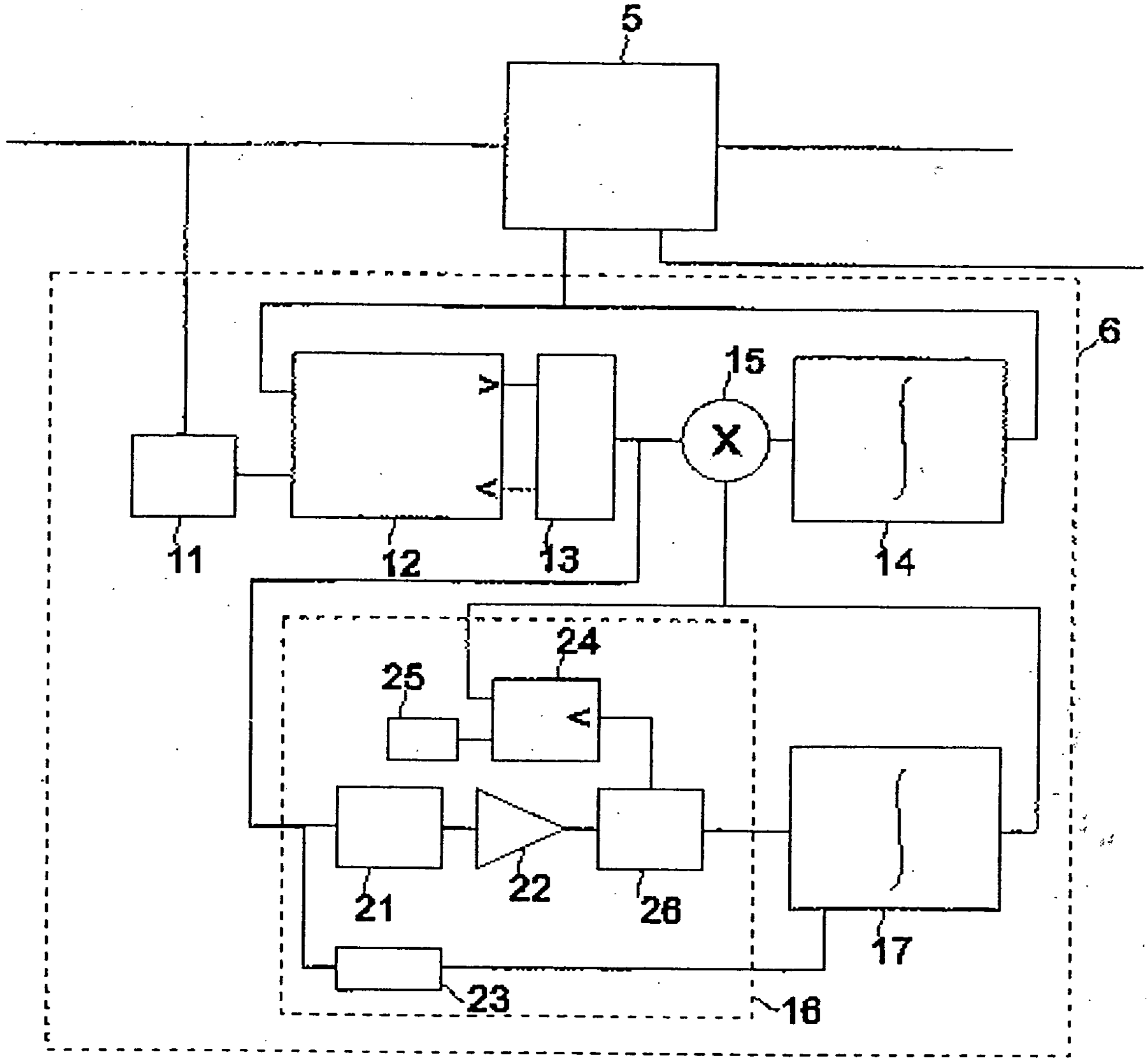

Fig. 3

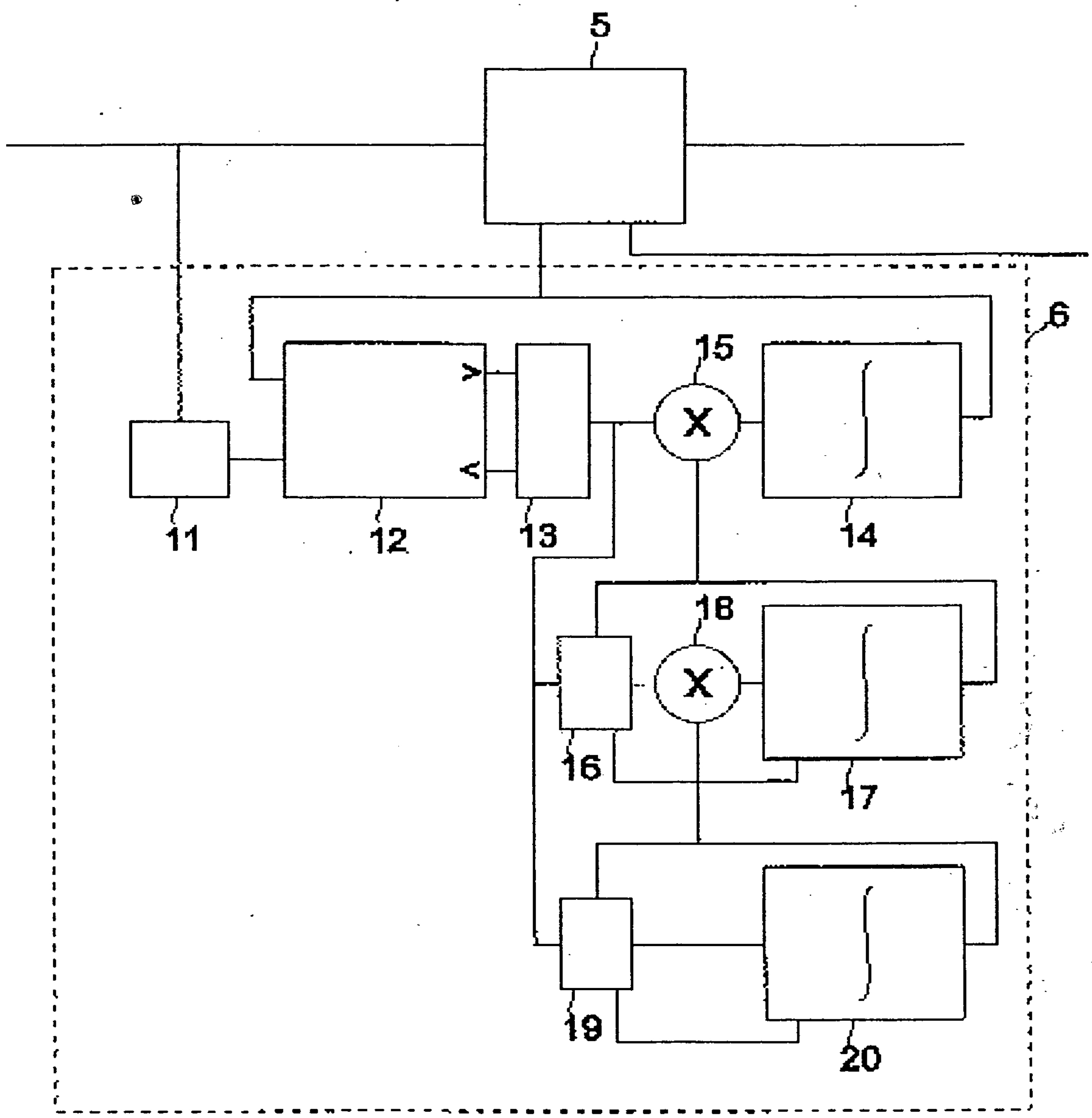

Fig. 4

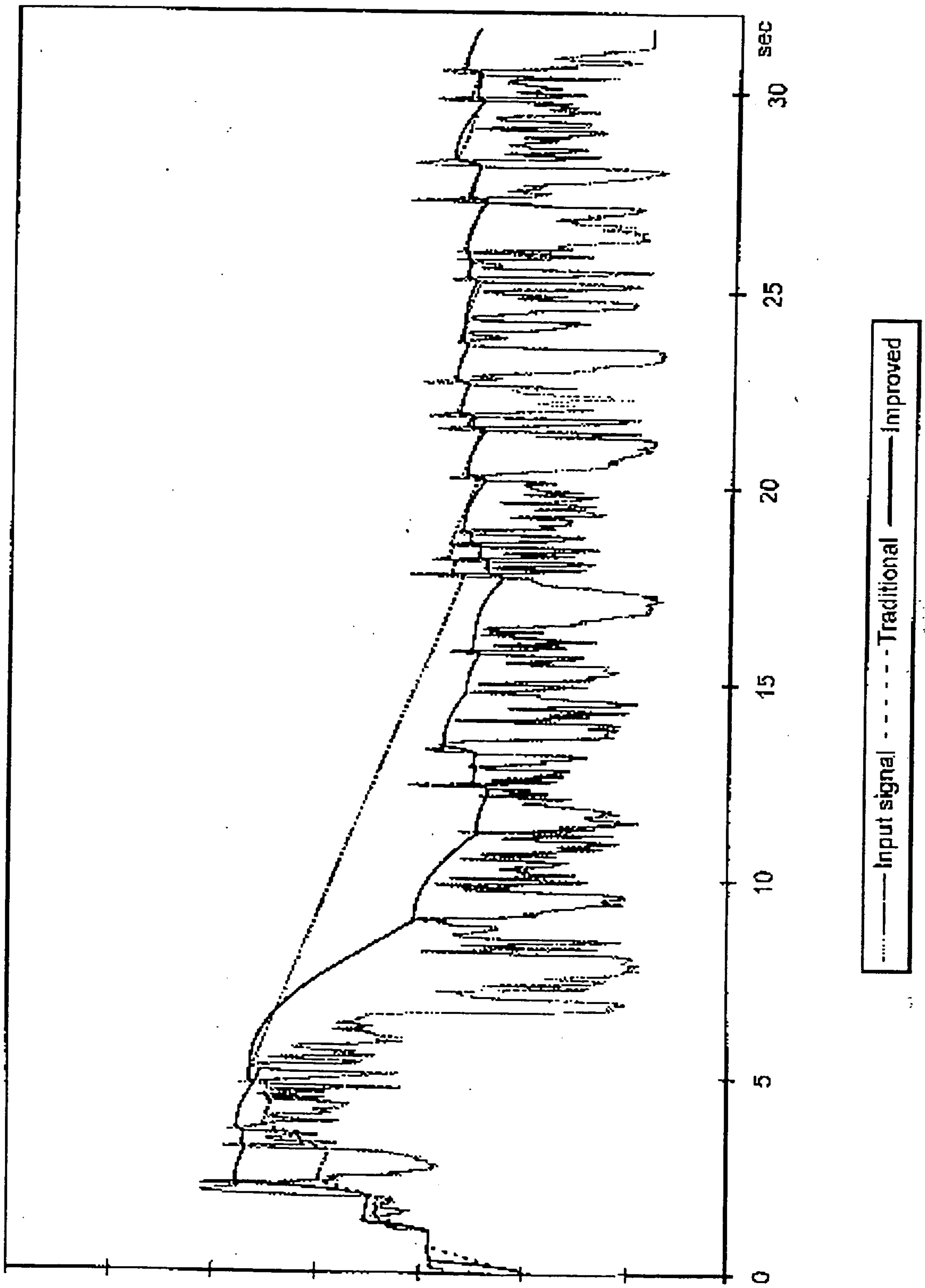

Fig. 5